MERCURY CONTROL WITH THE ADVANCED HYBRID PARTICULATE COLLECTOR

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MERCURY CONTROL WITH THE ADVANCED HYBRID PARTICULATE COLLECTOR

ABSTRACT

This project was awarded under U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) Program Solicitation DE-PS26-00NT40769 and specifically addresses Technical Topical Area 4 – Testing Novel and Less Mature Control Technologies on Actual Flue Gas at the Pilot Scale. The project team includes the Energy & Environmental Research Center (EERC) as the main contractor; W.L. Gore & Associates, Inc., as a technical and financial partner; and the Big Stone Plant operated by Otter Tail Power Company, host for the field-testing portion of the research.

Since 1995, DOE has supported development of a new concept in particulate control called the advanced hybrid particulate collector (AHPC). The AHPC has been licensed to W.L. Gore & Associates, Inc., and is now marketed as the *Advanced Hybrid*™ filter by Gore. The AHPC combines the best features of electrostatic precipitators (ESPs) and baghouses in a unique configuration, providing major synergism between the two collection methods, both in the particulate collection step and in the transfer of dust to the hopper. The AHPC provides ultrahigh collection efficiency, overcoming the problem of excessive fine-particle emissions with conventional ESPs, and it solves the problem of reentrainment and re-collection of dust in conventional baghouses. The AHPC appears to have unique advantages for mercury control over baghouses or ESPs as an excellent gas–solid contactor.

The objective of the original 5-task project is to demonstrate 90% total mercury control in the AHPC at a lower cost than current mercury control estimates. The approach includes bench-scale batch testing that ties the new work to previous results and links results with larger-scale pilot testing with real flue gas on a coal-fired combustion system, pilot-scale testing on a coal-fired combustion system with both a pulse-jet baghouse and an AHPC to prove or disprove the research hypotheses, and field demonstration pilot-scale testing at a utility power plant to prove scale-up and demonstrate longer-term mercury control.

This project, if successful, will demonstrate at the pilot-scale level a technology that would provide a cost-effective technique to accomplish control of mercury emissions and, at the same time, greatly enhance fine particulate collection efficiency. The technology can be used to retrofit systems currently employing inefficient ESP technology as well as for new construction, thereby providing a solution to a large segment of the U.S. utility industry as well as other industries requiring mercury control.

The scope of work was modified to include an additional sixth task, initiated in April 2003. The objective of this task is to evaluate the mercury capture effectiveness of the AHPC when used with elemental mercury oxidation additives, a spray dryer absorber, and novel baghouse sorbent inserts downstream of the fabric filter.

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ACI	activated carbon injection
AHPC	advanced hybrid particulate collector
COHPAC	compact hybrid particulate collector
CMM	continuous mercury monitor
DOE	U.S. Department of Energy
EB	eastern bituminous
EERC	Energy & Environmental Research Center
ESP	electrostatic precipitator
FF	fabric filter
FGD	flue gas desulfurization
IAC	iodine-impregnated activated carbon
LOI	loss on ignition
LOS	Leland Olds Station
NETL	National Energy Technology Laboratory
OH	Ontario Hydro
PJBH	pulse-jet baghouse
PRB	Powder River Basin
PTC	particulate test combustor
PTFE	polytetrafluoroethylene
SDA	spray dryer absorber
SEA	sorbent enhancement additive
TDF	tire-derived fuel
WSB	western subbituminous

MERCURY CONTROL WITH THE ADVANCED HYBRID PARTICULATE COLLECTOR

EXECUTIVE SUMMARY

Since 1995, the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) has supported development of a new concept in particulate control called the advanced hybrid particulate collector (AHPC). The AHPC has been licensed to W.L. Gore & Associates, Inc., and is now marketed as the *Advanced Hybrid*™ filter by Gore. The AHPC combines the best features of electrostatic precipitators (ESPs) and baghouses in a unique configuration, providing major synergism between the two collection methods, both in the particulate collection step and in the transfer of dust to the hopper.

The objective of this project is to demonstrate 90% total mercury control with commercially available sorbents in the AHPC at a lower cost than current mercury control estimates. The approach includes three levels of testing: 1) bench-scale batch testing that ties the new work to previous results and links results with larger-scale pilot testing with real flue gas on a coal-fired combustion system, 2) pilot-scale testing on a previously proven combustion system with both a pulse-jet baghouse (PJBH) and an AHPC to prove or disprove the research hypotheses, and 3) field-demonstration pilot-scale testing at a utility power plant to prove scale-up and demonstrate longer-term mercury control.

Initial bench-scale results were in good agreement with previous data. Results showed that the SO_2 and NO_2 concentration effects are additive and have a significant effect on sorbent performance. This finding should facilitate predicting sorbent performance in real systems when the SO_2 and NO_2 concentrations are known.

An initial field test of the 2.5-MW AHPC at the Big Stone Plant was completed the first week of November 2001. Results showed that the average inlet mercury speciation for seven samples was 55.4% particulate bound, 38.1% oxidized, and 6.4% elemental. A carbon injection rate of 24 kg of carbon sorbent/million m^3 of flue gas (1.5 lb of carbon sorbent/million acf) resulted in 91% total mercury collection efficiency, compared to 49% removal for the baseline case.

Following the initial field test, additional bench-scale tests, as well as the first planned pilot-scale tests, were completed. A key finding from the bench-scale tests was that the fixed-bed sorbent-screening tests using simulated flue gas were in good agreement with similar tests sampling real flue gas. This suggests that as long as the main flue gas components are duplicated, the bench-scale fixed-bed tests can be utilized to indicate sorbent performance in larger-scale systems.

In the pilot-scale tests, a baseline comparison was made between the AHPC and a PJBH in terms of the mercury speciation change across the device and the amount of mercury retained by the fly ash. Results showed that for both devices there was very little capture of mercury by the

fly ash. There was some increase in oxidized mercury, but no significant differences were noted between the AHPC and pulse-jet modes of operation.

Even though the same coal was used in the pilot-scale and initial field tests, there was a significant difference in inlet mercury speciation. For the pilot-scale tests, results were more similar to what is typically expected for Powder River Basin (PRB) coals in that most of the mercury was elemental, with little mercury capture by the fly ash. In contrast, for the November 2001 field test, there was much more oxidized than elemental mercury and significant mercury capture by the fly ash. Possible reasons for the difference include higher carbon in the field ash, somewhat higher HCl in the field flue gas due to the cofiring of tire-derived fuel (TDF), possible variation in the coal, cyclone firing for the field compared to pulverized coal firing for the pilot tests, longer residence time for the field tests, and a finer particle size for the field test.

During April–June 2002, a number of baseline and carbon injection tests were completed with Belle Ayr PRB subbituminous coal, one of the coals currently being burned at Big Stone. For the baseline case, approximately 70% of the inlet mercury was elemental, approximately 23% oxidized, and 2% or less was associated with particulate matter. Very little natural mercury was captured across the AHPC for the baseline tests, and the level of oxidized mercury increased only slightly across the AHPC during baseline operation.

With carbon injection, a comparison of short and long residence time in the AHPC showed that somewhat better mercury removal was achieved with longer residence time. No evidence of desorption of mercury from the carbon was seen upon continued exposure to flue gases up to 24 hours. This suggests that desorption of captured mercury from the carbon sorbent is not a significant problem under these flue gas conditions with the low-sulfur subbituminous coal.

At a carbon-to-mercury ratio of 3000:1, from 50% to 71% total mercury was removal achieved. When the ratio was increased to 6000:1, the removal range increased to 65%–87%. These results are highly encouraging because this level of control was achieved for the very difficult case with predominantly elemental mercury and very little natural capture of mercury by the fly ash.

A longer-term field test was completed with the 2.5-MW field AHPC August 6 through September 6, 2002. Carbon injection and CMM (continuous mercury monitor) measurements were continuous (24 hours a day) for the entire month except for an unplanned plant outage from August 29 to September 2. The primary goal of the work was to demonstrate longer-term mercury control with the AHPC and evaluate the effect of carbon injection on the AHPC operational performance. Another goal of the test was to evaluate the effect of supplemental TDF burning on the level of mercury capture for comparison with results from the previous test completed in November 2001.

The inlet mercury speciation during the August 2002 tests averaged 17% particulate bound, 32% oxidized, and 51% elemental. The significant difference in mercury speciation between the August and November 2001 field data is likely the effect of a higher rate of cofiring of TDF with the coal during the November test.

In the November 2001 tests, 49% mercury capture was seen for the baseline conditions without carbon injection. The August tests indicated only 0%–10% mercury capture with no carbon injection. Again, the most likely explanation is the much higher TDF cofiring rate and higher HCl in the flue gas for the November test.

Addition of activated carbon at a rate of 24 kg of carbon sorbent/million m^3 of flue gas (1.5 lb of carbon sorbent/million acf) resulted in an average of 63% mercury removal in the August tests without any TDF cofiring. A small TDF cofiring rate of about 23 tons a day resulted in an increase in mercury collection to 68%. At the highest TDF rate seen in the August tests of 150–177 tons a day, mercury removal of up to 88% was achieved. This compares with 91% removal seen during the November tests when the TDF feed rate was in the range from 90 to 250 tons a day. These results indicate that TDF cofiring has the effect of increasing the level of mercury control that can be achieved with a low carbon addition rate.

One of the main objectives of the August tests was to assess the effect of carbon injection on longer-term AHPC performance. When the carbon was started on August 7, there was no perceptible change in pressure drop or bag-cleaning interval. Similarly, there was no change in the K_2C_i value that relates to how well the ESP portion of the AHPC is working. These results indicate that low addition rates of carbon will have no perceptible effect on the operational performance of the AHPC.

Another short field test was completed with the 2.5-MW AHPC at the Big Stone Plant November 19–22, 2002, to coincide with the first test conducted at the inlet and stack of the full-scale *Advanced Hybrid*™ filter after it came online October 26, 2002. The primary purpose of the test was to evaluate the effect of injecting a small amount of HCl into the flue gas along with the activated carbon. Results showed that without supplemental HCl injection and a low carbon injection rate of 24 kg of carbon sorbent/million m^3 of flue gas (1.5 lb of carbon sorbent/million acf), from 65% to over 90% total mercury removal was achieved. This is somewhat better than the results seen in the monthlong continuous test in August 2002. Part of the reason could be the higher temperatures in the AHPC during August, which typically were in the range of 132°–143°C (270°–290°F) compared to 121°C (250°F) for the November 2002 tests.

Little or no effect was seen with the supplemental HCl injection. This is somewhat surprising because an extensive amount of bench-scale sorbent work has demonstrated the benefit of HCl for capturing elemental mercury in a simulated flue gas over the temperature range of 107°–188°C (225°–370°F). However, the benefit of additional HCl may be marginal in cases where there is already a sufficient amount of HCl present to achieve good mercury control.

During October–December 2002, a 5.7-m^3/min (200-acfm) pilot-scale test was also completed with Springfield bituminous coal. The purpose of this test was to evaluate mercury control with the AHPC with a high-sulfur bituminous coal. The Springfield bituminous coal produced a flue gas that was high in all of the acid gases including SO_3, and most of the inlet mercury was in an oxidized form. A number of short- and longer-term tests with the NORIT Americas Darco FGD carbon at temperatures ranging from 135° to 160°C (275° to 320°F) showed that this sorbent is completely ineffective at mercury control under these conditions.

This is in contrast to the extensive testing conducted previously with the AHPC and subbituminous coal, where up to 90% mercury capture was seen at a low carbon addition rate. The data are consistent with previous bench-scale testing that has shown that flue gas conditions are critical to the mercury capture ability of an activated carbon.

The previous field studies performed in November 2001 and August 2002 showed there was a correlation between Hg^{2+} concentration in the flue gas and the amount of TDF fed into the boiler. However, because of the variability of the TDF feed rate, it was difficult to quantify the TDF effect on mercury removal. A 1-week pilot-scale test was conducted on the 5.7-m^3/min (200-acfm) EERC AHPC where the coal feed rate and the TDF feed rate were precisely controlled.

Cofiring of TDF with the subbituminous coal had a significant effect on mercury speciation at the inlet to the AHPC. Firing 100% coal resulted in only 19% oxidized mercury at the inlet compared to 47% cofiring 5% TDF (mass basis) and 85% cofiring 10% TDF. The significant increase in oxidized mercury may be partly the result of increased HCl in the flue gas with the TDF. However, since the actual increase of measured HCl was only a few ppm, other changes in combustion conditions or flue gas components may also be responsible for the increase in oxidized mercury.

The TDF not only enhances mercury oxidation in flue gas but also improves mercury capture when combined with FGD carbon injection. With 100% coal, test results have shown from 48% to 78% mercury removal at a relatively low FGD carbon addition rate of 24 kg of carbon/million m^3 (1.5 lb of carbon/million acf). With TDF, results showed from 88% to 95% total mercury removal with the same carbon addition rate while cofiring 5%–10% TDF. These results are consistent with previously reported results from the 2.5-MW pilot-scale AHPC.

W.L. Gore & Associates, Inc., has developed an innovative technology for control of mercury emissions in flue gas streams. Specifically, the configuration involves a mercury control filter placed inside the existing particulate control filter bag, essentially a bag-within-a-bag concept.

A week of testing was completed with two different cartridge filters on the 5.7-m^3/min (200-acfm) AHPC in March 2003. The filters were installed inside of the four cylindrical all-polytetrafluoroethylene (PTFE) bags in the AHPC unit. Operationally, the mercury filter elements did not appear to impair the pulse cleaning of the bags. Initial tests with these cartridges showed that nearly 100% mercury capture could be achieved, but early breakthrough results were observed. Another week of testing was planned for fall 2003, but Gore has made the recent decision to discontinue development of this technology. Instead, the last week of testing will focus on evaluation of the amount of mercury captured on the perforated plates compared to the total mercury capture across the AHPC.

Another 1-month field test was completed during May–June 2003 with the 2.5-MW AHPC unit at the Big Stone Plant to demonstrate long-term mercury control with the AHPC and evaluate the impacts of various operating parameters such as filtration velocity, carbon feed rate, and carbon in-flight time on mercury control.

The inlet mercury vapor concentration in the flue gas during the May 2003 test ranged from 4.98 to 10.6 μg/m^3 with 20%–70% Hg^0. The variation in mercury speciation is likely caused by varying coal as well as the intermittent cofiring of TDF and waste seeds. The May 2003 test indicated 0%–30% mercury inherent capture with no carbon addition, typical for western subbituminous coal.

At low carbon feed concentrations ranging from 1 to 3 lb/Macf, the AHPC demonstrated high overall mercury collection efficiencies from 65% to 95%. When compared with other research results, the AHPC clearly demonstrated higher mercury removal efficiency than an ESP under the same FGD carbon feed rate. The overall Hg removal with the AHPC was similar to a baghouse or COHPAC (compact hybrid particulate collector).

The project Scope of Work has been modified to include an additional sixth task, initiated in April 2003. The objective of this task is to evaluate the mercury capture effectiveness of the AHPC when used with elemental mercury oxidation additives and a spray dryer absorber and with novel baghouse sorbent inserts downstream of the fabric filter. This modification will test the application of the AHPC to capture mercury in flue gases that contain low levels of acid gases typical of lignite and spray dryer baghouse applications. Two technologies will be tested: mercury oxidation and a sorbent.

Additional efforts to the existing scope of work involve testing advanced Hg oxidation and control agents for spray dryer and baghouse applications for control of elemental mercury emissions typical of North Dakota lignite-fired systems. The activities include 1) Hg oxidation upstream of a lime-based spray dryer AHPC combination in order to control mercury emissions using dry scrubbers and 2) field testing of mercury sorbent technology at a North Dakota power plant using a slipstream baghouse. Note that this is a change in the scope of work reflecting the Gore's recent decision to cease its mercury research program.

The pilot-scale Niro spray dryer system installed on a 580-MJ/h (550,000-Btu/h) combustion system upstream of a baghouse was included in pilot-scale test runs accomplished in December 2003. Several additives and sorbents were tested for mercury control on a Center coal flue gas generated in the EERC particulate test combustor (PTC). The sorbents tested included DARCO® FGD activated carbon supplied by NORIT Americas, Inc.; an EERC-treated activated carbon; and Amended Silicate™ developed by ADA Technologies, Inc.. The furnace additives tested were NaCl, $CaCl_2$, and a third additive for which the EERC is assessing intellectual property issues.

Modifications to the existing baghouse chamber were nearly completed during this quarter. The baghouse will be mounted on a flatbed trailer for ease of transport and installation at any location. The trailer was purchased and is being modified so that the baghouse will remain stable during long-term operation at a host utility.

MERCURY CONTROL WITH THE ADVANCED HYBRID PARTICULATE COLLECTOR

1.0 INTRODUCTION

This project was awarded under U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) Program Solicitation DE-PS26-00NT40769 and specifically addresses Technical Topic Area 4 – Testing Novel and Less Mature Control Technologies on Actual Flue Gas at the Pilot Scale. The project team includes the Energy & Environmental Research Center (EERC) as the main contractor; W.L. Gore & Associates, Inc., as a technical and financial partner; and the Big Stone Plant operated by Otter Tail Power Company, which is hosting the field-testing portion of the research.

Since 1995, DOE has supported development of a new concept in particulate control called the advanced hybrid particulate collector (AHPC). The AHPC has been licensed to W.L. Gore & Associates, Inc., and is now marketed as the *Advanced Hybrid*™ filter by Gore. The AHPC combines the best features of electrostatic precipitators (ESPs) and baghouses in a unique configuration, providing major synergism between the two collection methods, both in the particulate collection step and in the transfer of dust to the hopper. The AHPC provides ultrahigh collection efficiency, overcoming the problem of excessive fine-particle emissions with conventional ESPs, and it solves the problem of reentrainment and re-collection of dust in conventional baghouses. In Phase II of the DOE-funded AHPC project, a 2.5-MW-scale AHPC was designed, constructed, installed, and tested at the Big Stone Plant. For Phase III, further testing of an improved version of the 2.5-MW-scale AHPC at the Big Stone Plant was conducted to facilitate commercialization of the AHPC technology. The AHPC appears to have unique advantages for mercury control over baghouses or ESPs as an excellent gas–solid contactor.

An additional task designed to evaluate the mercury capture effectiveness of the AHPC when used with elemental mercury oxidation additives and a spray dryer absorber and with novel baghouse sorbent inserts downstream of the fabric filter was initiated in April 2003 with DOE funding. The project Scope of Work has been modified to incorporate this change.

The current mercury control with the AHPC involved testing of sorbent injection upstream of the AHPC to demonstrate 90% total mercury control. This modification will test the application of the AHPC to capture mercury in flue gases that contain low levels of acid gases typical of lignite and spray dryer baghouse applications. Two technologies will be tested: mercury oxidation and an adsorbent.

Additional efforts to the existing scope of work involve testing advanced Hg oxidation and control agents for spray dryer and baghouse applications for control of elemental mercury emissions typical of North Dakota lignite-fired systems. The activities include 1) Hg oxidation upstream of a lime-based spray dryer AHPC combination in order to control mercury emissions using dry scrubbers and 2) field-testing of the W.L. Gore mercury adsorbent technology at a North Dakota power plant using a slipstream baghouse.

1.1 Background

Testing at the EERC has been conducted through the addition of oxidizing agents to the fuel that allow for the enhancement of activated carbon sorbent properties for mercury emission control. The addition of salts has been shown to oxidize elemental mercury, as shown in Figure 1. The results of the addition of materials with coal at very low levels along with the activated carbon injection (ACI) upstream of an ESP + fabric filter (FF), AHPC, and ESP only are illustrated in Figure 2. The first part of the figure shows the baseline data of mercury emission ranging from 9 to 12 μg/Nm^3, with 80%–90% of the mercury being in elemental form. The second case is ACI followed by the addition of Additive 2, showing a reduction in mercury emissions by 90%. The third case is the AHPC that produced nearly 90% control efficiency. The final ESP-only case potential improvement over past results obtained with the ESP-only case illustrated in Figure 2. This technology also has the potential to improve the dry flue gas desulfurization (FGD) baghouse control efficiency (1).

Recently, short-term testing conducted at Stanton Station by Great River Energy and EPRI indicated the injection of chloride salts resulted in increased Hg oxidation in the flue gas (2). Mercury oxidation of up to 70% was observed at a salt injection rate that resulted in an HCl concentration of 110 ppm in the flue gas. In addition, the injection of salt resulted in enhanced removal of mercury across the spray dryer absorbers (SDA) baghouse with removal efficiencies of up to 50% without ACI. Additional testing at this lignite-fired unit also showed that the use of ACI upstream of the SDA–FF system provided significantly better performance when small amounts of sorbent enhancement additive (SEA) were added in the furnace. Therefore, the use of these additives upstream of the APCD can improve Hg capture both by conversion of the Hg^0 to

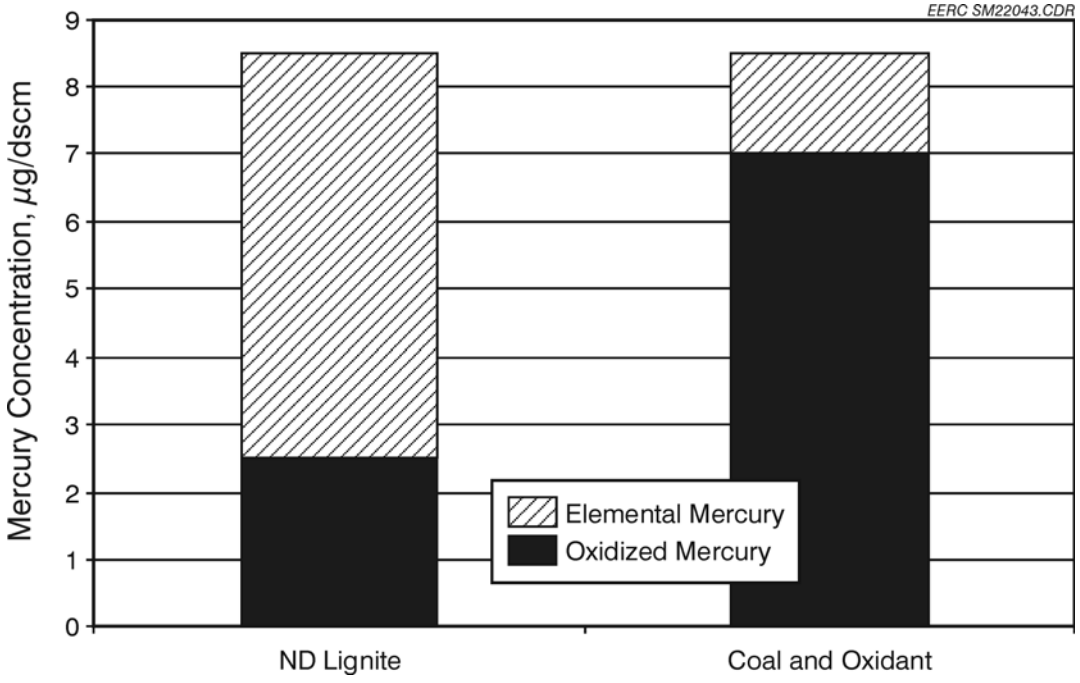

Figure 1. Impact of addition of chlorine-containing additive with fuel on the proportion of elemental and oxidized mercury.

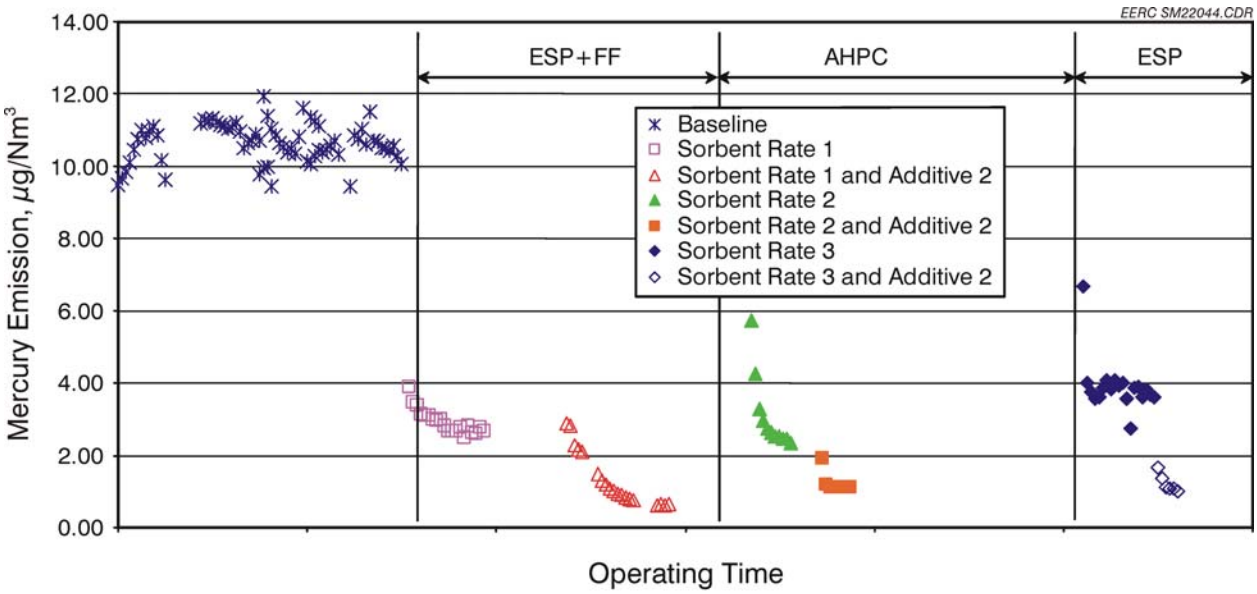

Figure 2. Mercury emissions for activated carbon injection combined with additives.

the more easily removed Hg^{2+} form and by enhancing the reactivity of Hg^0 with activated carbons (ACs) and other sorbents. Testing at Stanton Station also indicated an increased pressure drop across the air preheater as a result of injecting the salt materials. This is of significant concern since the chlorine-containing species can react with alkali and alkaline-earth elements present in the ash to produce low-melting-point phases that contribute to the deposition problem. Efforts must be conducted to determine the minimum quantity of oxidizing agent necessary to oxidize mercury in order to minimize the deposition problems.

2.0 EXPERIMENTAL

2.1 Objective and Goals

The overall project objective is to demonstrate 90% total mercury control with commercially available sorbents in the AHPC at a lower cost than current mercury control estimates. The specific objective for the add-on task is to reduce mercury emissions by 50%–90% in flue gases typically found in North Dakota lignite-fired power plants at costs of one-half to three-quarter of current estimated costs.

Test goals include the following:

- Determine if the bench-scale mercury breakthrough results can be duplicated when real flue gas is sampled.

- Compare the level of mercury control between the AHPC and a pulse-jet baghouse (PJBH) with sorbents under similar conditions at the 55-kW (200-acfm) pilot scale.

- Demonstrate 90% mercury capture for both a western subbituminous and an eastern bituminous coal.

- Demonstrate mercury capture with the 2.5-MW (9000-acfm) AHPC at Big Stone.

- Demonstrate 90% mercury capture over a longer time (3 months) with the 2.5-MW (9000-acfm) AHPC at Big Stone.

- Evaluate the mercury capture effectiveness of the AHPC when used with elemental mercury oxidation additives and a spray dryer absorber (Task 6 add-on).

- Evaluate the mercury capture effectiveness of the AHPC and baghouses when used with novel baghouse sorbent inserts downstream of the FF (Task 6 add-on).

2.2 Planned Scope of Work (revised February 2004)

To meet the objectives, the work was organized into six tasks:

- Task 1: Project Management, Reporting, and Technology Transfer
- Task 2: Bench-Scale Batch Testing
- Task 3: Pilot-Scale Testing
- Task 4: Field Demonstration Pilot Testing
- Task 5: Facility Removal and Disposition
- Task 6: Pilot and Field Testing in Spray Dryer and Baghouse Applications (6.0 add-on)

2.2.1 Task 1 – Project Management, Reporting, and Technology Transfer

Task 1 includes all of the project management requirements, including planning, coordination among team members, supervision of tests, review of results, meeting attendance, and all aspects of reporting.

2.2.2 Task 2 – Bench-Scale Batch Testing

The bench-scale tests are for the purposes of verifying previous results, expanding on the SO_2 and NO_2 concentration effect, linking the synthetic gas results to the results with real flue gas, and screening sorbents.

The 30 tests planned with the bench-scale unit are divided into three series that follow a logical progression. The purpose of the first series of tests is to ensure that results obtained by the EERC and others can be duplicated and, second, to include SO_2 and NO_2 as variables. Series 1 tests, shown in Table 1, are intended to verify the previous bench-scale work and expand on the SO_2 and NO_2 concentration effect. In previous work, no tests were completed in which both

Table 1. Bench-Scale Series 1 – SO_2 and NO_2 Concentration

Test No.	Sorbent Type	Temp., °C (°F)	Sorbent Concentration, mg	Flue Gas	SO_2, ppm	HCl, ppm	NO, ppm	NO_2, ppm
1	FGD	135 (275)	150	Simulated	1600	50	400	20
2	FGD	135 (275)	150	Simulated	500	50	400	20
3	FGD	135 (275)	150	Simulated	200	50	400	20
4	FGD	135 (275)	150	Simulated	1600	50	400	10
5	FGD	135 (275)	150	Simulated	500	50	400	10
6	FGD	135 (275)	150	Simulated	200	50	400	10
7	FGD	135 (275)	150	Simulated	1600	50	400	5
8	FGD	135 (275)	150	Simulated	500	50	400	5
9	FGD	135 (275)	150	Simulated	200	50	400	5
10	FGD	135 (275)	150	Simulated	Repeat test to be selected			

SO_2 and NO_2 were reduced at the same time. In all of these tests, the inlet Hg^0 concentration is typically 15 μg/m^3, and each test is run for approximately 4 h. The 150 mg of NORIT FGD activated carbon sorbent is equivalent to a sorbent-to-mercury ratio of 3700 after 3 h of exposure. This concentration has been shown to provide consistent results in previous testing and is sufficient to accurately measure the amount of mercury in the spent sorbent for mass balance closure. The Series 1 tests were previously completed, and results were reported in the January–March 2002 Quarterly Report.

The second series of bench-scale tests (Table 2) was for the purpose of comparing the bench-scale fixed-bed results sampling real flue gas to those obtained with simulated flue gas for both western subbituminous (WSB) and eastern bituminous (EB) coals. The simulated flue gas concentrations are based on the actual concentrations measured in the combustion tests. In addition, tests with lower sorbent concentrations were planned with flue gases matched to the two coals to assist in selecting the best sorbent concentrations for the pilot-scale tests. The real flue gas tests are part of the first two pilot-scale tests in Task 3, using a slipstream bench-scale system sampling flue gas from the particulate test combustor (PTC).

Tests 11–14 of the Series 2 tests were previously completed, and results were presented in the January–March 2002 Quarterly Report. Tests 16 and 17 were completed in the October–December 2002 quarter as part of pilot-scale tests with an EB coal. There are no current plans to complete Test 15 because it does not appear that 90% mercury control could be achieved by reducing the carbon concentration from what has already been tested. Tests 18–20 will also not be completed because the pilot-scale tests reported with the bituminous coal showed that the FGD carbon was ineffective at mercury control for the flue gas conditions produced from combustion of this specific bituminous coal.

Table 2. Bench-Scale Series 2 – Real Flue Gas Comparison

Test No.	Sorbent Type	Temp., °C (°F)	Sorbent Concentration, mg	Flue Gas	SO_2, ppm	HCl, ppm	NO, ppm	NO_2, ppm
11	FGD	135 (275)	150	Real	Flue gas from western coal			
12	FGD	135 (275)	150	Real	Duplicate test of western coal			
13	FGD	135 (275)	150	Simulated*	400	4	300	5
14	FGD	135 (275)	150	Simulated Duplicate*	400	4	300	5
15	FGD	135 (275)	50	Simulated*	400	4	300	5
16	FGD	135 (275)	150	Real	Flue gas from eastern coal			
17	FGD	135 (275)	150	Real	Duplicate test of eastern coal			
18	FGD	135 (275)	150	Simulated*	1000	50	400	10
19	FGD	135 (275)	150	Simulated Duplicate*	1000	50	400	10
20	FGD	135 (275)	50	Simulated*	1000	50	400	10

* Simulated flue gases will be determined from actual flue gas measurements during combustion tests; values shown are estimates.

The third series of bench-scale tests (Table 3) was for the purpose of screening alternative sorbents. The iodine-impregnated activated carbon (IAC) sorbent was initially chosen because of the excellent results seen in some of the previous EERC pilot-scale tests, especially at higher temperatures from 121° to 177°C (250° to 350°F). IAC also appears to be better at capturing Hg^0 than FGD. However, since IAC is more costly than FGD, it must be effective at lower concentrations than FGD. The plan was to evaluate the IAC for both a subbituminous and a bituminous coal at two concentration levels and two temperatures. However, since pilot-scale tests (reported later in the April–June 2003 Quarterly Report) showed no improvement in mercury removal over the FGD carbon, there is no basis for doing these IAC tests.

The plan was to potentially conduct four additional screening tests on other promising alternative sorbents to be selected based on new information and availability, and then, depending on initial results, further evaluate them in pilot-scale testing in Task 3. Several versions of a noncarbon-based sorbent developed outside the EERC were tested. Initial results showed poor mercury removal which may have been partially due to the preparation and testing procedures, but there are no current plans for further testing of this specific sorbent. The one remaining possible alternative sorbent approach is the cartridge insert idea (explained in more detail in Section 3.2). However, because of the limitation of scale, this will be tested only with the pilot-scale AHPC under Task 3 rather than in the bench-scale system.

2.2.3 Task 3 – Pilot-Scale Testing

Eight weeks of testing were planned under Task 3. A week of testing included an 8-h heatup period on gas and then approximately 100 h of steady-state operation firing coal. This allows for four 24-h test periods where the PTC is operated around the clock. The originally

Table 3. Bench-Scale Series 3 – Sorbent Type

Test No.	Sorbent Type	Temp., °C (°F)	Sorbent Concentration, mg	Flue Gas	SO_2, ppm	HCl, ppm	NO, ppm	NO_2, ppm
21	IAC	135 (275)	150	Simulated*	400	4	300	5
22	IAC	135 (275)	50	Simulated*	400	4	300	5
23	IAC	135 (275)	150	Simulated*	1000	50	400	10
24	IAC	135 (275)	50	Simulated*	1000	50	400	10
25	IAC	163 (325)	150	Simulated*	400	4	300	5
26	IAC	163 (325)	150	Simulated*	1000	50	400	10
27	New No. 1 **	135 (275)	150	Simulated*	400	4	300	5
28	New No. 2 **	135 (275)	150	Simulated*	400	4	300	5
29	New No. 3 **	135 (275)	150	Simulated*	400	4	300	5
30	New No. 4 **	135 (275)	150	Simulated*	400	4	300	5

* Simulated flue gases will be determined from actual flue gas measurements during combustion tests; values shown are estimates.

** New sorbents will be selected based on background data and availability.

planned 6 weeks of tests are shown in Table 4. The first 2 weeks were for the purpose of generating baseline data without carbon injection for a bituminous and a subbituminous coal with both the PJBH and the AHPC. Each test duration was approximately 48 h. These tests were for the purpose of establishing the amount of mercury capture by fly ash and determining whether the amount of mercury capture is different between the PJBH and the AHPC. Another purpose was to establish the inlet and outlet speciated mercury concentrations and whether there was a change in mercury speciation across both devices. A second purpose for these baseline tests was to provide flue gas to support the bench-scale testing with real flue gas under Task 2.

Weeks 3 and 4 were designed to prove the ability of the technology to control mercury at the 90% level with a WSB coal. Week 5 was for testing mercury control in the AHPC with an EB coal.

Week 6 was for the purpose of testing alternative sorbents in the AHPC. The need for alternate sorbent testing is somewhat dependent on the results with the FGD sorbent. If 90% mercury capture was already demonstrated with both coals at a low sorbent concentration (for example, less than 3000:1), then there may be no need to further evaluate other sorbents. In this case, Week 6 would be cancelled, and testing with the field AHPC would proceed. However, if results with the FGD sorbent have not met expectations and other sorbents look more promising, or if other unanswered questions remain that could be tested in the pilot tests, Week 6 would be completed.

Weeks 7 and 8 were intended to test an innovative new sorbent technology developed by W.L. Gore & Associates, Inc., one of the project's sponsors and primary partners. The development of mercury adsorbents with capacities far greater than conventional activated

Table 4. Task 3 – Pilot-Scale Testing

Week/ Test	Purpose	Coal	Collection Device	Sorbent Type	C:Hg Ratio	Injection Method
1-1	Baseline	WSB	PJBH	None	NA[1]	NA
1-2	Baseline	WSB	AHPC	None	NA	NA
2-1	Baseline	EB	PJBH	None	NA	NA
2-2	Baseline	EB	AHPC	None	NA	NA
3-1	Hg capture, collection device	WSB	PJBH	FGD	3000[2]	Continuous
3-2	Hg capture, collection device	WSB	AHPC	FGD	3000[2]	Continuous
4-1	Hg capture, residence time	WSB	AHPC	FGD	3000[2]	Continuous
4-2	Hg capture, residence time	WSB	AHPC	FGD	3000[2]	Batch
5-1	Hg capture, residence time	EB	AHPC	FGD	3000[2]	Continuous
5-2	Hg capture, residence time	EB	AHPC	FGD	3000[2]	Batch
6-1	Sorbent type and concentration	WSB	AHPC	New No. 1[3]	3000[2]	Continuous[3]
6-2	Sorbent type and concentration	WSB	AHPC	New No. 1[3]	1000[2]	Continuous[3]
6-3	Sorbent type and concentration	WSB	AHPC	New No. 2[3]	3000[2]	Continuous[3]
6-4	Sorbent type and concentration	WSB	AHPC	New No. 2[3]	1000[2]	Continuous[3]
7	Sorbent type and concentration	WSB	AHPC	Gore[4]	NA	NA
8[5]	Plate capture vs. total capture	WSB	AHPC	FGD	3000[2]	Continuous[3]

[1] Not applicable.
[2] Estimated concentrations; actual concentration will be based on previous testing.
[3] To be selected.
[4] Bag insert within the AHPC.
[5] Newly added test.

carbon is the basis of this work. Specifically, the configuration involves a mercury control filter placed inside the existing particulate control filter bag, essentially a bag-within-a-bag concept. Prior testing, funded by Gore, at the U.S. Environmental Protection Agency (EPA) research facility in Research Triangle Park, North Carolina, has shown significant levels of both elemental and ionic mercury capture. This approach is highly compatible with the AHPC and offers many advantages as an alternative to the use of disposable activated carbon. The plan was to conduct two 1-week tests with the pilot-scale AHPC to evaluate the mercury capture performance of the Gore technology. The first week of tests was conducted with a subbituminous coal at an AHPC temperature of 149°C (300°F). However, since that time, Gore has discontinued development of this technology. An alternative Week 8 test will evaluate the amount of mercury collected on the perforated plates in the AHPC compound to the total mercury removal across the AHPC.

From the pilot-scale test matrix listed in Table 4, the first 3 weeks of testing with a WSB coal have all been completed (Tests 1-1, 1-2, 3-1, 3-2, 4-1, and 4-2). Results from the first week of testing were reported in the January–March 2002 Quarterly Report. Results from Weeks 2–4 were presented later in the April–June 2002 Quarterly Report. The Week 5 test results with an EB coal were presented in the October–December 2002 Quarterly Report. Because no other

alternative sorbent was identified, Week 6 of testing with the FGD carbon was completed cofiring tire-derived fuel (TDF) and presented in the April–June 2003 Quarterly Report. Initial results from Week 7 were presented in the April–June 2003 Quarterly Report. Week 8 testing is planned for the second quarter in 2004.

2.2.4 Task 4 – Field Demonstration Pilot Testing

Demonstration of mercury control with the AHPC at the 2.5-MW scale at a utility power plant is the next logical step toward proving the commercial validity of this approach. A total of 5 months of field tests was originally planned. The first month was planned for baseline testing without sorbent injection to establish the mercury concentration, speciation, and amount of fly ash capture as well as to compare mercury emissions at the plant stack with the AHPC outlet.

The second month of field tests was planned for the purpose of establishing the sorbent addition rate to achieve 90% mercury control. Depending on the level of success with the FGD sorbent in the field and the pilot-scale test results with alternative sorbents, the third month was planned for the purpose of evaluating alternative sorbents. If alternative sorbent testing is not done, then 3 months of longer-term testing with the FGD sorbent will be completed. The longer-term operation will establish whether there are any longer-term problems associated with sorbent injection, such as bag-cleaning problems. If alternative sorbents are tested during Month 3, then the longer-term demonstration testing will last only 2 months.

According to the planned work, testing with the 2.5-MW AHPC at the Big Stone Plant was not scheduled to begin until after completion of the first pilot-scale tests. However, the project team decided to conduct an initial field test the first week of November 2001 prior to the pilot-scale tests at the EERC.

The field test at Big Stone was completed the week of November 5–10, 2001, with baseline testing on the first day, followed by carbon injection in both AHPC and pulse-jet operational modes for the remainder of the week. The starting carbon addition rate was set at 24 kg of carbon sorbent/million m^3 of flue gas (1.5 lb of carbon sorbent/million acf), with the plan that it could be increased if necessary to achieve good mercury control. However, over 90% mercury control was seen at this carbon addition rate, so no testing was completed at higher carbon concentrations. The results from the November field test were previously reported in the October–December 2001 Quarterly Report.

An additional month of mercury control testing was completed with the 2.5-MW field AHPC August 6 – September 6, 2002. Carbon injection, along with continuous mercury monitor (CMM) measurements, was completed during the entire month except during an unplanned plant outage during the period from August 29 to September 2. Those results were presented in the July–September 2002 Quarterly Report.

Another short-term test was completed with the 2.5-MW AHPC on November 19–22, 2002, to coincide with stack mercury testing for the full-scale *Advanced Hybrid*™ filter at the Big Stone Plant. Those results were presented in the October–December 2002 Quarterly Report.

The final month of field testing was completed during May 6–June 3, 2003, and results were presented in the April–June 2003 Quarterly Report.

2.2.5 Task 5 – Facility Removal and Disposition

The field AHPC will be dismantled and removed at the end of this project if no further testing is anticipated in support of subsequent work at the Big Stone Plant. If further testing was to be completed with the field AHPC at another site (funded by possible subsequent projects), the AHPC components would be moved to that site. If no other AHPC testing is anticipated, the salvageable AHPC components will be returned to the EERC, and the larger steel components will be disposed of as scrap steel. The site will then be restored to its original condition. The Big Stone Plant will be responsible for removing the 24-in. ductwork that breeches the plant ductwork, electrical power lines, air supply lines, and communication lines once the project is complete.

2.2.6 Task 6 – Mercury Control with the Advanced Hybrid Particulate Collector

2.2.6.1 Subtask 6.1 – Mercury Control with Spray Dryer Scrubber Combined with AHPC or Baghouse

Pilot-Scale SDA Refurbishment. A pilot-scale SDA will be modified and installed on the EERC PTC to simulate the SDAs used in some North Dakota power plants.

Elemental Mercury Oxidation Additives. Potential Hg^0 oxidation additives will be evaluated using the PTC equipped with the refurbished SDA and AHPC. Pilot-scale testing will involve a North Dakota lignite coal with short-term (1–2-h) screening tests of several oxidation additives including chloride compounds (e.g., sodium chloride, hydrogen chloride, and calcium chloride) and potassium iodide, followed by longer-term (8–10-h) evaluations of two or more of the most promising additives. In most cases, the additives will be blended with the coals. Gaseous HCl will be injected into the PTC.

Hg^0 and total Hg levels will be measured on a nearly continuous basis using a CMM at the inlet and outlet locations of the SDA. Slaked lime slurry feed and the SDA product solids will be analyzed for Hg content. Additive blend ratios and injection rates will be varied to evaluate the effectiveness of additives to oxidize Hg^0. Economic analyses will be performed for the additives that are most effective.

2.2.6.2 Subtask 6.2 – Field Testing of Sorbents and Gore Technology

This task will test how effectively Hg can be captured by using a sorbent-based technology in conjunction with a PJBH at a power plant in North Dakota. This task work plan formerly included evaluation of a Gore technology consisting of a proprietary baghouse insert downstream of the FF that has shown a high potential to control Hg. However, Gore's recent decision to abandon their mercury research program has resulted in elimination of its inclusion in the planned scope of work. Additional sorbent evaluations will be accomplished in lieu of the Gore techology. An existing baghouse will be skid-mounted and transported to a power plant in

North Dakota and connected in slipstream fashion to allow for testing actual flue gases. Additions to the existing baghouse unit for remote field application will include a control room for remote operation, piping and flanges for connection to plant ductwork, a variable speed fan, and a sorbent injection system for Hg control. The PJBH can operate for much longer periods of time than can the pilot-scale AHPC.

The skid-mounted baghouse will be installed downstream of an existing PCD such as an ESP at a North Dakota power plant. CMMs will be used to measure Hg^0 and total Hg vapor at various monitoring ports in the system. Mercury sampling with the Ontario Hydro (OH) method will be conducted to provide Hg species information, dust loading, and particulate collection efficiencies. In certain cases, EPA Method 101A may be used to determine the total Hg (only) removed across the baghouse system.

3.0 RESULTS AND DISCUSSION

Activities during this quarter focused on preparation of the draft final report and Task 6.

3.1 Elemental Mercury Oxidation Additives

One week of short-term sorbent (Subtask 6.1) and furnace additive testing was accomplished in December 2003 to demonstrate mercury removal by sorbent injection combined with various oxidizing additives to simulate a scrubbed baghouse system. The 580-MJ/h (550,000-Btu/h) pulverized coal PTC unit was equipped with a Niro Inc. Production Minor Spray Dryer Model I and baghouse and fired with Center lignite coal. Table 5 summarizes the test matrix for the spray dryer–baghouse configuration. Based on previous pilot-scale testing results of ESP mercury removal effectiveness, three additives (NaCl, $CaCl_2$, and another for which the EERC is assessing the intellectual property issues) were evaluated. CMMs were set up at the inlet to the spray dryer upstream of the sorbent injection port at the outlet of the baghouse to monitor mercury vapor concentrations continuously throughout the 4-day test. Six OH method samples were collected at the same locations to verify CMM measurements and performance of the sorbents and additive injection. A Thermo Environmental Model 15C HCl analyzer was collocated with the CMMs upstream of the spray dryer inlet to measure changes in the chloride levels of the flue gas resulting from chlorine-containing furnace additives. A preliminary review of the data indicates increased HCl content in the flue gas with increasing NaCl addition in the furnace. This is the first time, to our knowledge, that HCl and mercury concentrations have been measured simultaneously in a coal combustion flue gas. The experimental data were reduced and interpreted during this quarter. The results will be reported in an upcoming quarterly report as well as in the project final report.

Table 5. Spray Dryer Test Sample Matrix (December 2004 run)

Mercury Oxidation Additive		Sorbent	
Type	Feed Rate, lb/Macf	Type	Injection Rate, lb/Macf
None	NA*	None	NA
None	NA	DARCO® FGD	1.84 – 11.02
None	NA	EERC-treated FGD	1.84 – 7.35
None	NA	Amended Silicate™	7.35
NaCl	3.67–11.02	None	NA
NaCl	3.67–11.02	DARCO® FGD	3.67
SEA 2	1.84–3.67	None	NA
SEA 2	1.84–3.67	DARCO® FGD	1.84
$CaCl_2$	3.67–11.02	None	NA
$CaCl_2$	3.67–11.02	DARCO® FGD	3.67

* Not applicable.

3.2 Baghouse Unit for Field Testing of Sorbents and Gore Technology

The construction of the trailer-mounted baghouse was completed this quarter. The unit was delivered to Basin Electric's Leland Olds Station (LOS) for sorbent injection activities. A photograph of the unit as mounted on the trailer at LOS is in Figure 3.

Sorbent injection activities using the EERC trailer-mounted sorbent injection system took place for 1 week at the end of the quarter. DARCO® FGD was injected at various rates at the inlet to the trailer-mounted baghouse. The test plan is presented in Table 6. During the weeklong test, air/cloth ratios were varied to achieve face velocities between 4 and 10 ft/min to investigate the effect of face velocity on mercury control. Sorbent injection is performed using a self-contained feed system, injecting sorbent into the 8-in. header at the entrance to the baghouse at rates ranging from of 2 to 10 lb/MMft^3, depending on the level of mercury reduced.

3.3 Planned Activities Through June 2004

- Data reduction and reporting from the December 2003 pilot-scale tests will be completed.
- Slipstream field tests using the portable baghouse will commence at LOS in April 2004.

Figure 3. The portable baghouse unit installed at Basin Electric's LOS for sorbent injection field tests.

Table 6. Portable Baghouse Slipstream Days 1 and 2 Test Matrix at LOS Unit 1

Mercury Oxidant		Sorbent		
Category	Injection Rate, μg/g[1]	Category	Injection Rate, lb/Macf (g/hr)	Baghouse Face Velocity, ft/min
None	NA	None	NA	6
None	NA	DARCO® FGD	1.9 (70)	6
None	NA	DARCO® FGD	2 (100)	8
None	NA	DARCO® FGD	2 (124)	10
Chlorine	500	DARCO® FGD	0.9 (34)	6
Chlorine	500	DARCO® FGD	0.9 (34)	8
Chlorine	300	DARCO® FGD	2 (100)	8

[1] Chlorine added to make the μg/g equivalent in the coal.

4.0 CONCLUSIONS

The applicability of three potential Hg sorbents (DARCO® FGD, Amended Silicate™, and EERC-treated FGD) and three Hg^0 oxidation and SEAs (NaCl, $CaCl_2$, and SEA 2) to improve the Hg(g) removal efficiency of a spray dryer–FF pollution control system was evaluated using a pilot-scale (580-MJ/hr [550,000-Btu/hr]) pulverized coal-fired unit. A Center lignite coal was burned in the unit while Hg(g) concentrations were measured using CMMs at the spray dryer inlet and FF outlet to evaluate Hg removal performance. The Hg sorbents and Hg^0 oxidation and sorbent enhancement additives were evaluated separately, and all except the Amended Silicate™ and EERC-treated FGD were also tested in combination. Test results are pending and will be reported in the next (April 1 – June 30, 2004) quarterly.

5.0 REFERENCES

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